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Field emission enhancement of DLC films using triple-junction type emission structure

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ABSTRACT

Negative Electron Affinity (NEA) of Diamond-like-Carbon (DLC) films has made DLC films a favorable candidate for field emission display (FED). It was suggested that triple-junction type structure could enhance the field emission characteristics. A triple junction is defined as the intersection of a semiconductor surface with a metal substrate in vacuum. In this study, field emission enhancement in triple junction type structures was investigated. As a metal substrate 5000 of Mo films were deposited. Then, 3000-4000 of DLC film was deposited as a semiconductor material. Thin film layers were made using a negative ion beam source. After the deposition, using an excimer laser, we removed the DLC layer and made circular shaped triple junction trenches with a diameter of 25–250 μm. The field emission characteristics such as I-V characteristics turn on voltage and emission lifetime data were obtained for a diode type field emission measurement system. Overall results show significantly enhanced performance of field emission characteristics such as uniform emission over patterned area, reduced turn on voltages and longer lifetimes can be achieved.

INTRODUCTION

Due to its advantages such as increased brightness, improved viewing angle and lower power consumption than Liquid Crystal Displays (LCD), Field Emission Display (FED) has become a big research and development field for the next generation display technology. In FED development, conventionally, molybdenum and Si tips were widely used as cold-cathode material[1]. However, Mo can be easily contaminated and has poor mechanical properties. Silicon is rather fragile and has low thermal conductivity[2]. Recently, DLC films become a favorable candidate for FED thanks to its Negative Electron Affinity (NEA), high thermal conductivity, chemical inertness and high hardness[3]. Also, field emission from DLC (diamond-like carbon) films is of particular interest because they can be made at room temperature, over large areas and on various kinds of substrates such as glass, metals, semiconductors, ceramics and polymers. Several years ago a new electron-emission mechanism so called triple-junction type emission for cold cathodes was proposed[4]. A triple junction is the intersection of a semiconductor surface with a metal substrate in vacuum. Unlike conventional mechanisms, in which electrons tunnel from a metal or semiconductor directly into vacuum, the electrons in the triple-junction type structure tunnel from a metal into diamond surface states, where they can be accelerated and ejected into vacuum.

EXPERIMENTAL SETUP

In this study, we prepared two different sets of samples; the conventional diode structure and the triple junction structure. As a metal substrate 5000 the Mo films were deposited. Then,

3000-4000 of DLC film was deposited on top of the Mo layer as a semiconductor material. Using an excimer laser, we selectively patterned the DLC layer producing circular triple junction features with diameter of 25 – 250 μm.

Film Deposition

DLC films used in this paper were made using a direct ion beam deposition technique. With a cryogenic pump (CTI-cryogenics) attached to the chamber, the base pressure was about 5×10^{-7} Torr. The chamber pressure was monitored using a thermocouple and an ion gauge. The typical operating pressure of the source with Argon plasma was on the order of 10^{-4} Torr. At the bottom, a commercial 8" magnetron sputter type negative ion source (SKION Corporation. Omnipotent series) was placed. In Molybdenum deposition, an 8-inch diameter and 0.25 inch thickness 99.999% Molybdenum target was used. At DLC deposition, the target is changed to 99.999% graphite target. The substrate holder with linear motion equipment had the capability to adjust the target-to-substrate distance. During the deposition, an 8-inch manual gate valve located between the cryo pump and the chamber controlled the pressure. To reduce the work function of the sputtering target, Cs vapor was introduced into the chamber. Detailed information about the source and mechanism of Cesium delivery is given elsewhere[5]. After the deposition, the surface morphology of the resultant DLC samples was analyzed using an AFM (Digital Instrument, Dimention3100). The typical Ra (mean roughness) of the film was 0.1nm. To create triple-junction type emission spots,

Field Emission measurement

A substantial part of this work has been the development of methods for reliable measurement of the field emission characteristics. For this purpose, we have built a field emission measurement system. All the measurement was performed inside a UHV chamber, which is capable of keep the base pressure lower than 1×10^{-7} Torr. Figure 2. is the schematic diagram of the system. The spacing between film and phosphor plate was fixed as 100 μm.

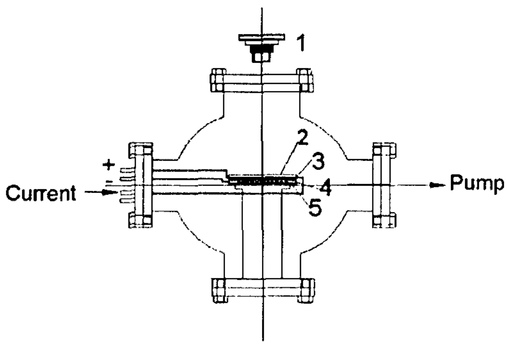


Figure 1. Field Emission measurement system: 1.Digital Camera, 2.Glass, 3.ITO, 4.Phosper plate and 5.Laser patterned DLC

RESULTS & DISCUSSION

Emitting area analysis

During the first stage of the experiment, the emission test was performed without any modification of the film. The very smooth, un-doped DLC films are poor field emitters regardless of their sp3 content, high NEA and low surface work function. At the measurement, usually the first emission starts from the edges of film (Figure2. (a)) or at the damaged surface area. The AFM image of the emitted area is shown Figure2. (b) and (d). The emitted spot shape like a crater with some portion of DLC film is taken off. After the first emission, the emitted area can maintain stable emission even after considerable amount of time (>10hr). This suggests that this kind of emission can be considered as a triple-junction type emission. The size of the craters is from 5 up to 150 μm.

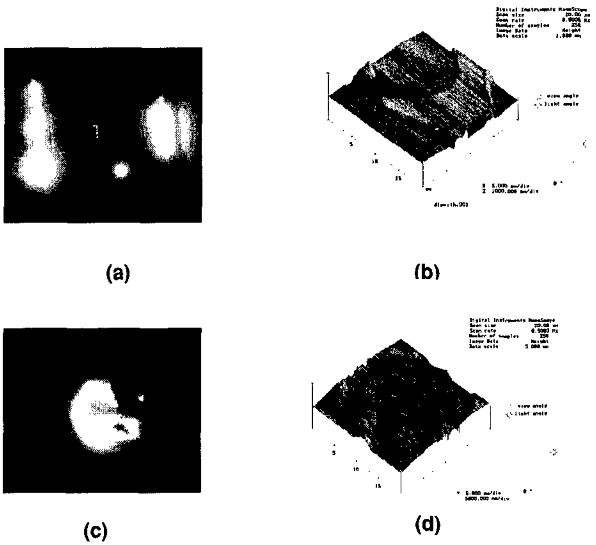
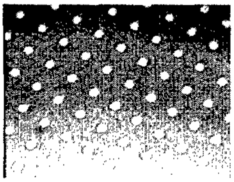
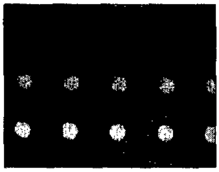


Figure 2. The field emission patterns of the DLC films and AFM images of the emitted spots: (a) DLC at 16 V/μm, (b) an emitted spot of (a), (c) DLC 20V/μm and (d) an emitted spot of (c).

Laser patterned DLC

Based on the results, we prepare a new sample set with laser-drilled holes. Using a laser, we took off DLC layer and produced Mo-DLC-Vacuum triple junctions. Figure 3 is the optical microscope image of the resultant film. In this case the diameter of the each hole was 100μm and space between each hole was 300 μm.



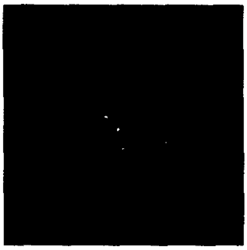


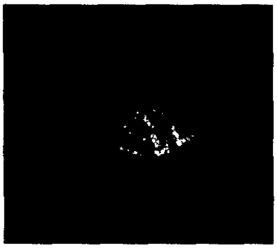
(a) (b)

Figure 3. The optical microscope images of DLC sample:

Emission Result of Patterned Sample

Using an excimer laser, we patterned a DLC coated 4" wafer with 25 - 250 μm holes. Figure 4 shows the emission pattern of the 100 μm-hole sample at 6V/μm (a) and at 12V/μm (b). The result shows that even though the whole area was coated with DLC, the patterned area emitted first. Since the high voltage was applied to the center of the wafer using a wire attached with silver epoxy, the central area of the wafer is brighter than edges. In other words, since the resistivity of the film is high, the voltage drop gets larger as the distance increases. This effect decreased when we used several wires to connect different regions of the sample.





(a) (b)

Figure 4. Emission images of the patterned DLC coating: (a) @ 6V/μm and (b) @ 12V/μm

Field emission measurement

The I-V characteristic of the sample was measured using a computer interfaced digital current meter (Extech, CMM-15). Figure 5 is a comparison of the J-V characteristic for DLC samples with and without patterning. Both samples were deposited at the same conditions. The result shows that the turn on voltage of the sample is enhanced from 12V/μm to 4V/μm with

patterning. Also the total emission current density at 15V/μm increased from 25 $\mu A/cm^2$ to 300 $\mu A/cm^2$ for the triple junction structure.

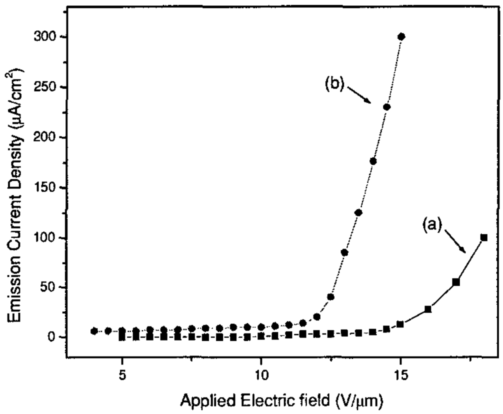
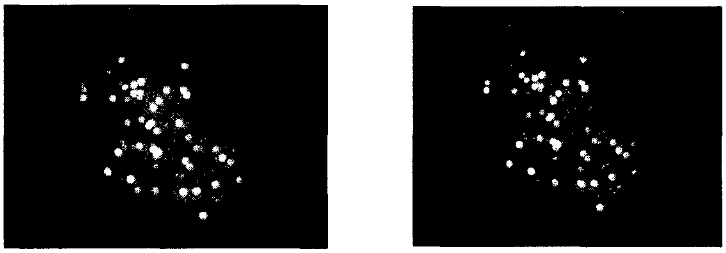


Figure5. J-V characteristic curve of DLC films: (a) DLC without any modification, (b) Laser patterned DLC (Hole diameter 100μm)

The lifetime study

In the last stage of this study, the lifetime of the emitting regions was investigated. Figure 6 shows the time dependence of a sample. Figure6 (b) was taken after 3 hours. Total emission current decreased approximately 15% after 3 hours and stays stable after that. Also emitting area decreases as time goes by. In the case of un-patterned DLC, total emission current density dropped about 33% after 3 hours.



(a) (b)

Figure 6. The emission images of the patterned DLC coating: (a) initial image and (b) image after 3hours

CONCLUSIONS

DLC films have many encouraging characteristics such as high negative electron affinity (NEA), high thermal conductivity, chemical inertness and high hardness. However, the very smooth, un-doped DLC films are known as poor field emitters regardless of their sp3 content and high NEA. After reviewing the emitted spots, a new approach to enhance field emission was tried. The new trial is based on the triple junction type field emission theory. Using an excimer laser, we patterned the surface of DLC coatings and produced triple junction structures. The result shows that triple junction structures can reduce the turn on voltage and increase the electron current density. Also the lifetime study shows that the emitted area can maintain emission stably even after a long period of time. The overall result shows that field emission enhancement can be achieved by producing triple junction structures on DLC films.

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